

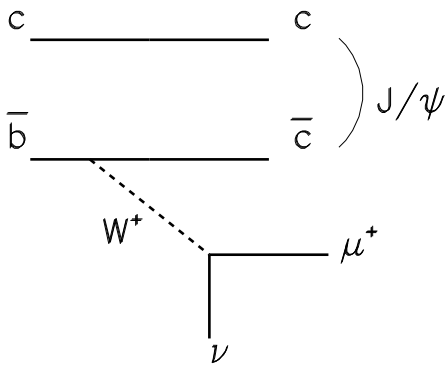
B_c The Last Meson

Measurements from CDF and D0 of the
pseudoscalar meson B_c .

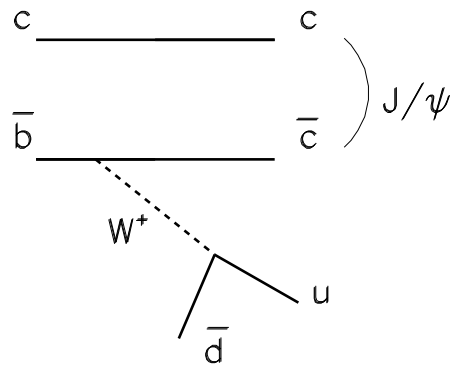
Moriond QCD, March 2005
Marj Corcoran
for the CDF and D0 collaborations.

Expected Decays of the B_c

The B_c is unique in that either of the quarks can decay, leaving the other as a spectator. One decay path is $\bar{b} \rightarrow \bar{c}W^+$, often leading to a final state containing J/ψ .



$$B_c^+ \rightarrow J/\psi \mu^+ \nu$$

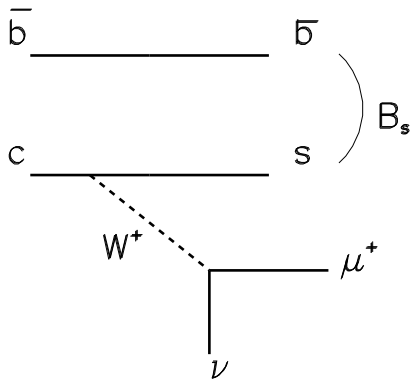


$$B_c^+ \rightarrow J/\psi \pi^+.$$

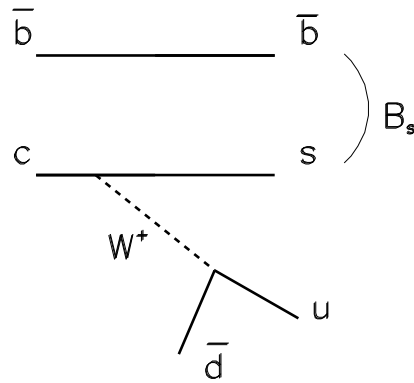
These are the two modes actually observed so far.

Expected Decays of the B_c

Other decay modes include $c \rightarrow sW^+$, with the b as spectator, leading to final states with B_s



$$B_c^+ \rightarrow B_s \mu^+ \nu$$



$$B_c^+ \rightarrow B_s \pi^+$$

And finally we could have $c\bar{b} \rightarrow W^+$ leading to a wide variety of final states including τ 's and multiple π 's.

Expected Properties of the B_c

There are many calculations of the expected mass and lifetime of B_c .

- Expectations for the mass range from 6.2 to 6.3 GeV/c².
- Expectations for the lifetime range from 0.4 to 1.4 ps.
Compare to the B^\pm lifetime of 1.67 ps.

The B_c is interesting because

- It probes the heavy quark potential in the region between the $b\bar{b}$ and $c\bar{c}$
- It has a rich spectroscopy of very narrow (keV) excited states.
- With enough statistics, it could provide flavor tagging for B_s studies

Observations of B_c

There have been three observations of B_c at the TeVatron.

- CDF made the first observation in Run I, in the mode $B_c \rightarrow J/\psi l \nu$ where $l = \mu$ or e .
Abe et al., Phys. Rev. Lett. **88** 2432 (1998).
Abe et al., Phys. Rev. **D58**, 112004 (1998).
- D0 has made an observation from RunII data in the mode $B_c \rightarrow J/\psi \mu X$. (*preliminary*)
www-d0.fnal.gov/Run2Physics/www/results/b.htm
- CDF has evidence for the exclusive final state $B_c \rightarrow J/\psi \pi$ in Run II data. (*preliminary*)
www-cdf.fnal.gov/physics/new/bottom/bottom.html



D0 Observation of $B_c \rightarrow J/\psi \mu X$

D0 has used 260 pb^{-1} of data to observe B_c in the semileptonic mode.

- Reconstruct a J/ψ from the dimuon data sample, requiring a good 3D vertex and a J/ψ mass constraint. Associate a third muon to the J/ψ vertex.
- For the background control sample, the third track is not tagged as a muon.
- Backgrounds arise from real J/ψ 's (either prompt or from B decays) with a third muon accidentally matching the vertex.
- Due to the missing neutrino, the proper time is not directly measured. The pseudoproper time (for the $J/\psi \mu$ system) must be corrected on average using signal Monte Carlo.

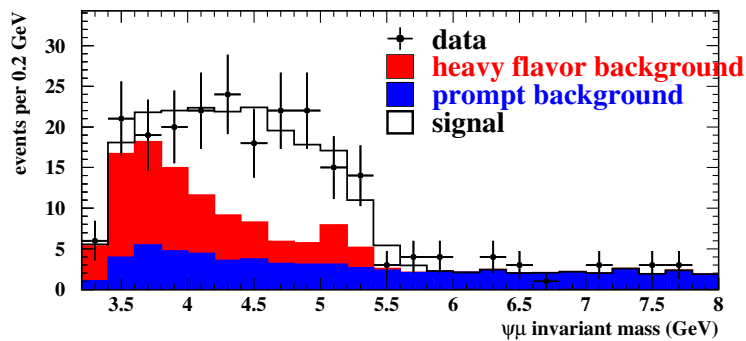
A likelihood fit to $M_{J/\psi \mu}$ and the lifetime yields an excellent fit to the data.



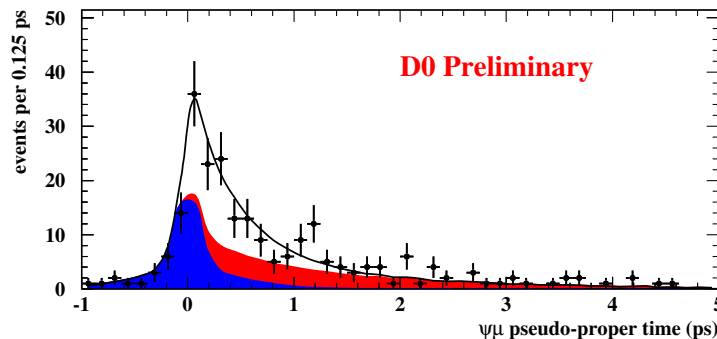
D0 Observation of B_c in $J/\psi\mu X$

Prompt backgrounds are from prompt J/ψ with an accidental muon track.

Heavy flavor backgrounds are from B decays with an accidental muon or a muon from the semileptonic decay of the other B .



$M_{\psi\mu}$



Pseudo-proper time

Results of the likelihood fit for $M_{\psi\mu}$ and pseudo-proper time, showing data, expected signal, and expected backgrounds.

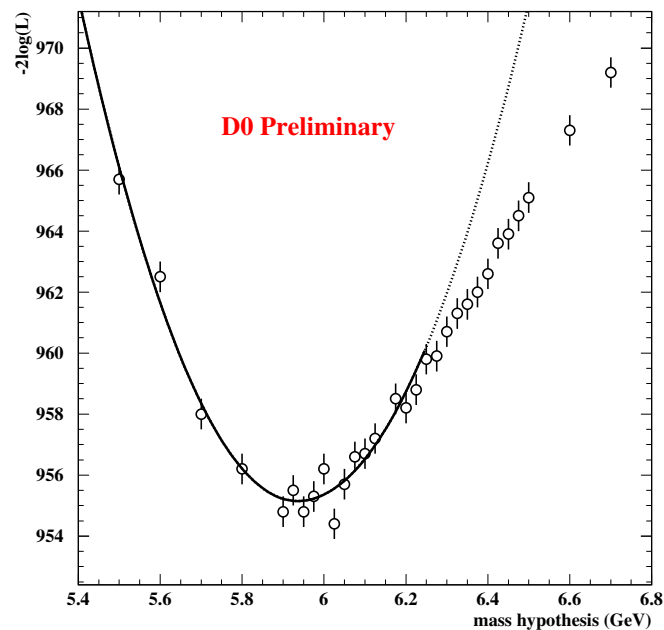
$95 \pm 12 \pm 11$ signal events.



D0 Observation of B_c in $J/\psi\mu X$

At each value of the mass, a combined unbinned likelihood fit is done for the mass and lifetime.

Likelihood vs. mass hypothesis



Mass hypothesis

The likelihood function shows a clear minimum at the favored mass of $5.95 \text{ GeV}/c^2$. The fit returns a lifetime of 0.45 ps.



CDF Evidence for $B_c \rightarrow J/\psi\pi$

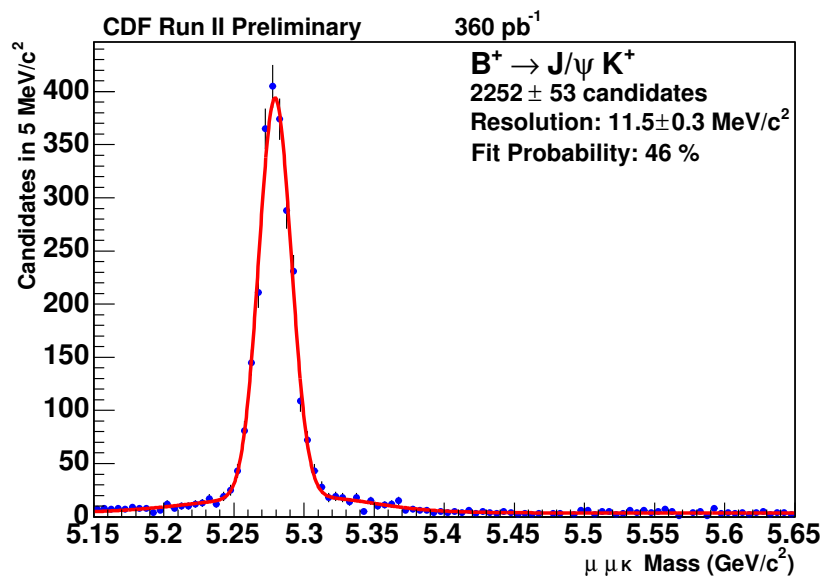
CDF has recently observed a 3.6σ signal for B_c in the exclusive final state $J/\psi\pi$.

- $J/\psi \rightarrow \mu\mu$ candidates are found at L3
- A third track, treated as a π , is constrained to form a good 3D vertex with the J/ψ . A mass constraint is also applied to the J/ψ
- Backgrounds include B_c decays which are not fully reconstructed!
- A **blind analysis** has been done by not revealing the true $M_{\psi\pi}$ until after selection criteria were established.
- Monte Carlo background studies were used to determine the minimum value of the significance function needed to claim an observation.



CDF Evidence for $B_c \rightarrow J/\psi \pi$

$B^+ \rightarrow J/\psi K^+$ is used as the reference mode to verify the understanding of the detector and Monte Carlo.



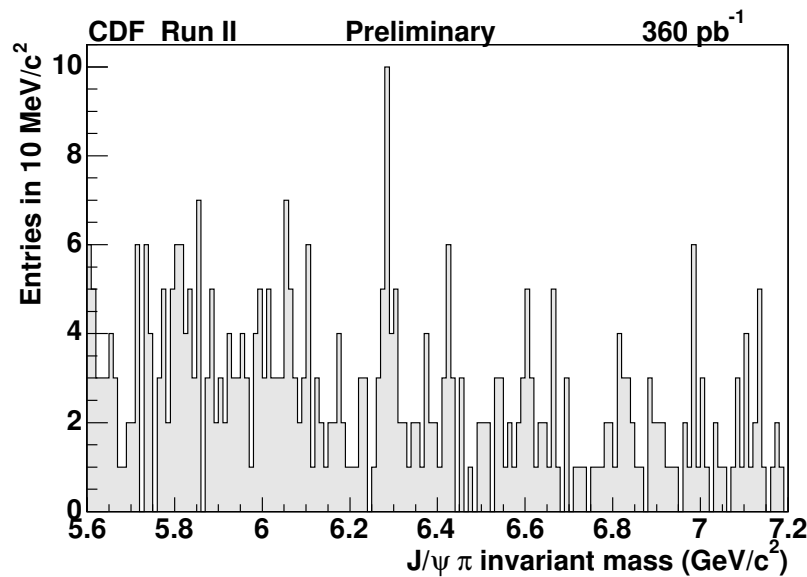
Distribution of $M_{\mu\mu K}$ for the reference mode $B^+ \rightarrow J/\psi K^+$. Cuts similar to the signal mode are applied.



CDF Evidence for $B_c \rightarrow J/\psi\pi$

The $M_{J/\psi\pi}$ mass distribution over the full mass region used in the search.

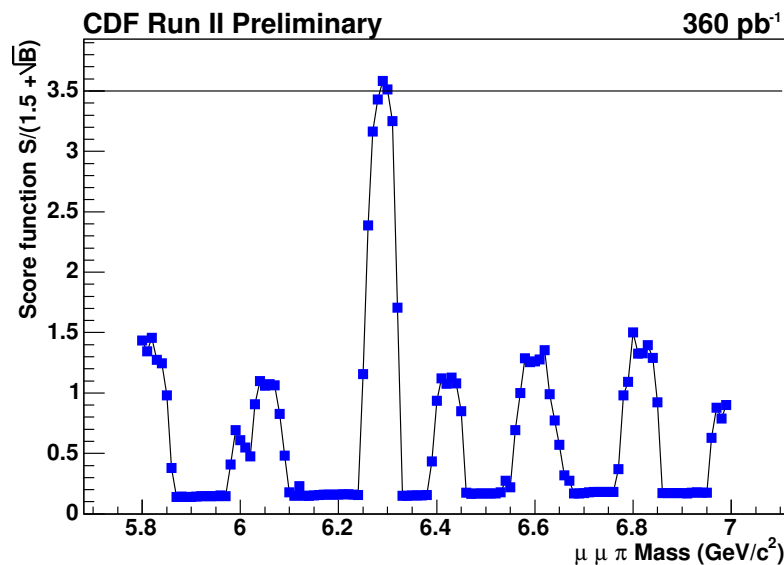
Identifying a signal in the presence of significant background is a challenge.





CDF Evidence for $B_c \rightarrow J/\psi\pi$

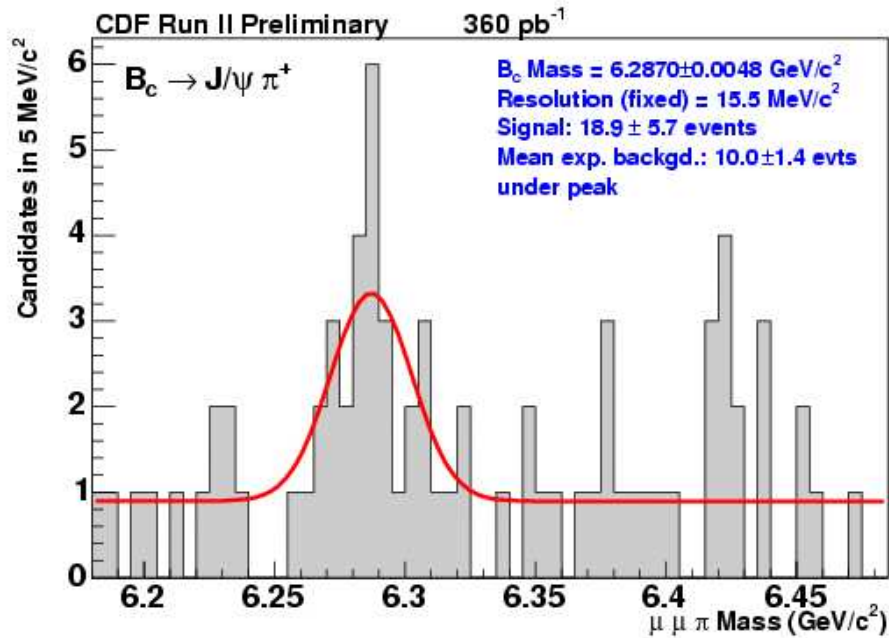
The minimum significance to claim a signal was determined to be 3.5 based on Monte Carlo background studies. Then they scanned the data in mass bins, fitting a signal Gaussian and background in each bin. The significance passed the cut in only one place:



Significance $\Sigma = S/(1.5 + \sqrt{B})$ as a function of $M_{\mu\mu\pi}$. A significance of 3.5 or more is required to claim observation.



CDF Evidence for $B_c \rightarrow J/\psi \pi$



$M_{\mu \mu \pi}$ distribution in the region selected by the significance scan. The results of an unbinned likelihood fit is shown. 18.9 ± 5.7 events, a 3.6 σ effect.

B_c mass = 6.2870 ± 0.0048 GeV/c²

Summary of B_c Observations

	\mathcal{L} (pb ⁻¹)	Signal Events
CDF Run I ($B_c \rightarrow J/\psi l \nu$)	110	$20.4^{+6.2}_{-5.5}$
D0 Run II ($B_c \rightarrow J/\psi \mu X$)	210	$95 \pm 12 \pm 11$
CDF Run II ($B_c \rightarrow J/\psi \pi$)	360	18.9 ± 5.7

	Mass(GeV/c ²)	Lifetime (ps)
CDF Run I ($B_c \rightarrow J/\psi l \nu$)	$6.4 \pm 0.39 \pm 0.13$ <i>(published)</i>	$0.46^{+0.18}_{-0.16} \pm 0.03$ <i>(published)</i>
D0 Run II ($B_c \rightarrow J/\psi \mu X$)	$5.95^{+0.14}_{-0.13} \pm 0.34$ <i>(preliminary)</i>	$0.45^{+0.12}_{-0.10} \pm .12$ <i>(preliminary)</i>
CDF Run II ($B_c \rightarrow J/\psi \pi$)	$6.287 \pm .0048 \pm .0011$ <i>(preliminary)</i>	not yet

Mass and lifetime well within the range of expectations.

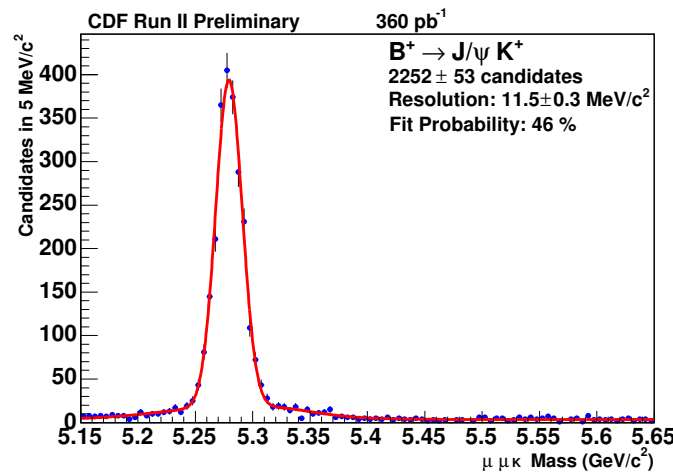
Future prospects

In the near term:

- Lifetime and event yield from CDF for $B_c \rightarrow J/\psi \pi$
- Semileptonic mode from Run II data from CDF.
- Finalized result from D0 on semileptonic mode.
- D0 result on $B_c \rightarrow J/\psi \pi$

More long term, we will see B_c in other decay channels and perhaps start to map out the excited states.

More generally, there is a very rich B physics program at the TeVatron!



Thanks to the people who did the work! And many thanks to those who provided me with plots and information—Sherry Towers (D0) and Vaia Papadimitriou (CDF).